CFD OF A SCREW BLADE FOR STANDALONE MICRO HYDRO GENERATOR

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ABSTRACT

Archimedean screw is one of the oldest hydraulic machines. Previously, this screw runner is used to lift water from lower part to upper part. In this modern era, Archimedean screw is used to generate electricity using the reverse concept of the old Archimedean screw. The efficiency of the screw blade is depend on the parameters of the screw blade. The main aim in this paper is to determine the efficiency of the Archimedean screw at different inclination angle and angle of attack of the blades. Re-inversed concept of the old Archimedean screw was used and using k-epsilon turbulence method was applied to study the fluid flow behavior. Comparison between theoretical design and CFD was done to obtain the most effective inclination angle and angle of attack between blades. Results show the inclination angle 23.58º and angle of attack 75º was the most reasonable design. In future can be more determine on the orientation angle for future research in Archimedean screw.

ABSTRAK

Archimedes skru adalah salah satu mesin hidraulik yang tertua. Sebelum ini, Archimedes skru digunakan untuk mengalirkan air dari bahagian bawah ke atas. Manakala pada zaman sekarang, Archimedes skru digunakan untuk menjana tenaga elektrik melalui konsep yang bertentangan dengan skru Archimedean lama. Tujuan utama dalam kertas kerja ini adalah untuk menentukan kecekapan skru Archimedean pada sudut kecenderungan yang berbeza dan sudut antara bilah. Konsep bertentanggan dari konsep skru Archimedean lama digunakan dan kaedah k-epsilon pergolakan telah digunakan untuk mengkaji kelakuan aliran cecair. Perbandingan antara reka bentuk teori dan CFD telah dilakukan untuk mendapatkan kecekapan skru yang paling berkesan antara sudut kecenderungan dan sudut antara bilah. Keputusan menunjukkan sudut kecenderungan 23,58º dan sudut antara bilah 75º adalah reka bentuk yang paling munasabah. Penyelidikan dalam sudut orientasi pada masa depan dalam Archimedean skru lebih menetukan.

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F	Fore
V	Velocity
P	Power output
β	Angle of attack
α	Orientation Angle

LIST OF ABBREVIATION

CFD	Computational Fluid Dynamic

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Malaysia has many potential renewable energies such as mini / micro hydro, biomass energy, solar energy, wind energy, geothermal energy and ocean energy. For micro hydro, it use the potential of the water to rotate the turbine and generator then convert into electrical energy. In Malaysia the average of water resource potential has a higher discharge and low head, so it is suitable to develop a low head turbine in Malaysia.

In this, a research on Archimedes screw is been done. The Archimedean screw is still new to be developed in Malaysia. This screw operates with low rotation speed and can generate electricity up to 500kW. The Archimedes screw has many advantages such as; do not require special control system, environmentally friendly and easy in construction.

It has been discovered that the performance of the screw if affected by the parameters of the screw. It is important to determine the parameters in order to get high performance of the screw. By this, a research is been carried on Archimedes screw in the aim to determine the effect of angles between the blades and orientation angles of the screw blade in the performance of the Archimedes screw in generating a small-scale of electricity.

1.2 PROBLEM STATEMENT

Developing Archimedean screw is very important in today's micro hydro system world. Archimedean screw is very easy to install and very low maintenance is required.Developing Archimedean screw in rural areas can generate small amount of electricity which can be used for wide purpose. Unfortunately, the efficiency of the Archimedean screw differs in different parameters. The efficiency changes at different angles, the horizontal angles between the land and the angles between the blades, cause an investigation need to be done before install the Archimedes screw.

1.3 OBJECTIVE

The objectives of the project are as follows :

i. To design three screw blade model using CAD.
ii. To study the screw blade characteristics at steady flow using Ansys CFX.
iii. To validate obtain result with experimental method from other researcher.
iv. The best design which as better efficiency is chosen as a base model.

1.4 PROJECT SCOPES

The scopes of the project are as follows :

i. Design three designs of screw blade with different parameters for comparison.
ii. Setup suitable boundary conditions for the simulation. Assume the fluid flow as steady flow.
iii. Run analysis using CFD application which isAnsys CFX to obtain results.
iv. Compare the obtained computational results with experimental results.

1.5 SIGNIFICANT OF STUDY

Computational Fluid Dynamics (CFD) is done to save cost and time of a project.From this research the efficiency of the screw blade can be analysed and the output scale of a screw blade can be can be calculated. This research will help to increase the importance of usage of computational results to analysis a certain experiment with high cost and long duration.

CHAPTER 2

LITERATURE REVIEW

2.1 COMPUTATIONAL FLUID DYNAMICS (CFD)

Computational fluid dynamics (CFD) is a computer simulation that analyzes systems for fluid flows, heat transfer, and phenomena such as chemical reactions. The rapid development of computational power and CFD technique becomes more and more relevant to the industrial applications, and this method has been applied in the area of the aerospace industry , meteorology (weather prediction), and external environment of buildings (wind loads and ventilation) commonly. CFD has many advantages over experiment-based approaches, such as reduction of lead times and costs of new designs, study systems under hazardous conditions, systems that are impossible to study with controlled experiments and, the unlimited level of detail of the results.

There are also problems with CFD. The physics are complex and the result from CFD is only as good as the operator and the physics embedded. With today's computer power, there is a limitation of grid fineness and the choice of solving approach (DNS, LES and turbulence model). This can result in errors, such as numerical diffusion, false diffusion and wrongly predicted flow separations. The operator must then decide if the result is significant. While presently, CFD is no substitute for experimentation, it is a very helpful and powerful tool for problem solving.

When working with CFD a number of different steps are followed. These steps are illustrated in figure 2.1.

Figure 2.1: The CFD process flow

The first step is to create geometry (with CAD). This is often already done by other departments or done by scanning a model. The geometry cannot have any holes, it has to be airtight, and unnecessary things in the CAD model that do not affect the flow has to be removed to save computer power. This is called CAD cleanup. The next step is to generate a mesh and this is often done automatically by a meshing program. Then the flow is simulated by a solver. After the simulation is ready, it is time for post processing. Post processing involves getting drag and lift data, and analyzing the flow.

2.2 CFD METHODS

There are many models in CFD such as laminar, k-omega, transientand more. The models used for turbulence will be k-epsilon and k-omega. K-epsilon is one of the most common models used for turbulence models. K-epsilon has two transport equations which represent the turbulence flow properties which mean it is a two equation model. The transport variable has two, the turbulent kinetic energy and turbulent dissipation.

K-EPSILON

For turbulent kinetic energy k

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+P_k+P_b-\rho\epsilon-Y_M+S_k \qquad 2.1$$

For dissipation ϵ

$$\frac{\partial}{\partial t}(\rho\epsilon)+\frac{\partial}{\partial x_i}(\rho\epsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial\epsilon}{\partial x_j}\right]+C_{1\epsilon}\frac{\epsilon}{k}\left(P_k+C_{3\epsilon}P_b\right)-C_{2\epsilon}\rho\frac{\epsilon^2}{k}+S_\epsilon \qquad 2.2$$

The k-epsilon that were using in CFD for this study is called the renormalized group k-epsilon. Yakhot and Orszag are the first to investigate the renormalized group analysis of turbulence in 1986. In 1992, by removing the smallest scales of turbulence, a turbulence model was developed that gives improvement in modeling turbulence at high Reynolds number (Schleicher, 2012).

2.3 HISTORY OF ARCHIMEDEAN SCREW

The screw pumps we are using today were to be the oldest pumps for the carrier of water. In the 3rd century, Archimedes, the Greek mathematician and physicist, invented the original screw pump.He named it upon his name called the "Archimedian Screw". It was a hand operated, spiraled tube set at an incline. The main purpose of the screw is to carry the water from lower part to upper part.

In the 4th century, the Romans started to use the water supply systems. For this they applied the archimedian Screw in their highly advanced systems.The Romans also used the archimedian screw pumps for irrigation and drainage work. Screw pumps also found use in ore mines in Spain.Before the Archimedes screw is employed, the Roman’s driven man and animals to run the system.

In the 14th century, screw pumps reappeared as a means of conveying liquid and constituted the first rebirth of Archimedes' ancient pump. Historical records refer to its use with artificial fountains. This rebirth was short-lived with the development ofreciprocating plunger pumps which had their heyday during the 19_{th} century and were used in the development of public water supply systems. Reciprocating plunger pumps were later replaced with centrifugal pumps.

Screw pumps with their ability to pump relatively large quantities of water at low lifts still found one obvious application as adrainage pump in low-lying areas, such as the reclaimed land areas of the North Sea and Baltic Sea. During this era the screwswere constructed of wood and were powered by use of wind force with windmills.

Present rebirth of the modern day screw pump dates back to the 1920's where their primary use was drainage pumps. In1930 there were some 300 screw pump installations in use in the Netherlands for draining low-lying ground. It wasn't until afterWorld War II that screw pumps were seriously applied for handling wastewaters. Since this time, their use has grown rapidly.

In present, the Archimedean screw is used to generate electricity from the fluid flow. The concept used is the reverse of the actual Archimedes screw, which is first used to lift water, from bottom to top.In the new era, the water flow downwards which means from top to bottom. The water flow is then rotates the screw blade where the kintic energy is thenconverted to electrical energy by using the generator (Berk, 2009).

2.4 TYPES OF HYDRO TURBINES

There are many types of hydro turbines. The type of turbine used for particular application depends on the head and flow rates seen by the turbine. Types of turbines commonly used in today’s world are Kaplan, Pelton and Francis turbines. Pelton turbines used for application at high head and Francis turbine at mid head.Kaplan and Archimedean screw used in the choice at low head. Figure below shows head, flow rate and power output that can be generate by each hydro turbines.

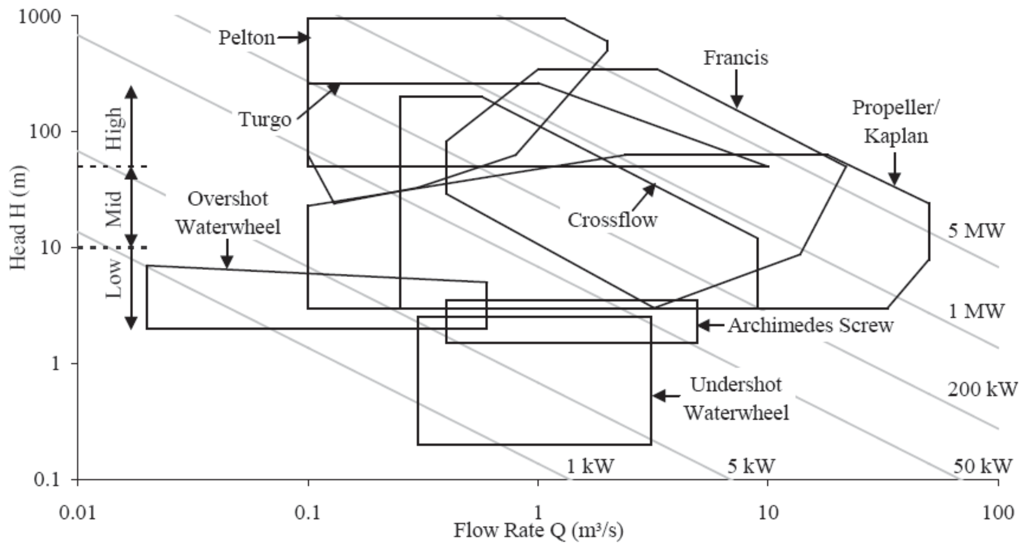

Figure 2.2 : Hydropower turbine application range chart

Source: Stergiopoulou et al., 2009

2.5 ADVANTAGES OF USING ARCHIMEDEAN SCREW

There are many advantages in using Archimedean screw as hydrodynamic screw. The most important features are :

2.5.1 High efficiency

Because of the flat efficiency curve the efficiency is high in a wide range of flows. Varying flowsand water heads have a small influence on the efficiency. The archimedean screw generator does not need a grease pump for the lower bearing which further increases efficiency (Babcock, 2010).

2.5.2 Simple and Reliable

The Archimedean screw generator, consist of a few wear parts. The screw generator has a low rotational frequency resulting in low wear. Since its not complex it is not hard to handle and can last for a longer time (Babcock, 2010).

2.5.3 Fish Friendly

Several test showed the fish friendliness of the Archimedean screw. In Holland, Canada, USA and other countries the Spaans Archimedean screw is used as a fish ladder by pumping fish (Babcock, 2010).

2.5.4 No screen is necessary

Only a simple 100-120mm bar screen is used to prevent large items enters the screw generator. This saves costs, prevent head loss and allow fish passage (Babcock, 2010).

2.5.5 Low Maintenance

Due to the simple and robust design, Archimedean screw generator installations require minimum maintenance (Babcock, 2010).

2.5.6 No Cleaning Service Required

Cleaning of the screw generator is not necessary. The generator is self-cleaning. No efficiency loss due to dirt builds up in the intake area (Babcock, 2010).

2.6 TYPES OF TROUGH FOR ARCHIMEDEAN SCREW

The Archimedean screw generator can be supplied with various trough types. The choice is depending on the existing civil structure. Below the two most common types are shown. The choice can also be a combination because every unit can specifically be designed to suit existing civil layouts.

2.6.1 Concrete Trough

The trough is in this case made out of concrete, by using the screw to form it's own trough. The concrete trough is the classic design. A trough roughly 50 mm larger than the outer diameter of the screw pump body is initially formed. After completion of installation of the screw and grouting of the bearings and drive base plates the required trough diameter is obtained by rotating the screw with a temporary screed bar fitted, slowly rotating and applying a concrete screed until the correct trough profile has been achieved. Figure 2.3 are example of Concrete trough (Babcock, 2010).

Figure 2.3 : Concrete Trough

Source: Spaans Babcock, 2010

2.6.2 Steel Trough

In certain circumstances the construction of a screwed concrete trough is not practical and a prefabricated steel trough liner can be provided. Anchors are attached to the back side of the trough and after positioning and fixing of the trough mass concrete is applied to form the final construction. Both the concrete trough and steel trough liner options require the provision of a separate drive mounting. This trough construction gives a medium amount of civil costs but a little higher mechanical cost. Figure 2.4 below show the examples for steel trough (Babcock, 2010).

Figure 2.4 : Steel Trough

Source: Spaans Babcock, 2010

2.7 HEAD AND FLOW

Wherever there is a flow of water falls from a higher level to a lower level, hydraulic power can be generated. This may occur where a stream runs down a hillside, or a river passes over a waterfall or man-made weir, or where a reservoir discharges water back into the main river. The vertical fall of the water, known as the “head”, is essential for hydropower generation; fast-flowing water on its own does not contain sufficient energy for useful power production except on a very large scale, such as offshore marine currents. Hence two quantities are required: a Flow Rate of water Q, and a Head H. It is generally better to have more head than more flow, since this keeps the equipment smaller. The Gross Head (H) is the maximum available vertical fall in the water, from the upstream level to the downstream level. The actual head seen by a turbine will be slightly less than the gross head due to losses incurred when transferring the water into and away from the machine. This reduced head is known as the Net Head. Sites where the gross head is less than 10 m would normally be classed as “low head”. From 10-50 m would typically be called “medium head”. Above 50 m would be classed as “high head”. The Flow Rate (Q) in the river, is the volume of water passing per second, measured in m3 /sec. For small schemes, the flow rate may also be expressed in litres/second where 1000 litres/sec is equal to 1 m^3/sec (The British Hydropower Association, 2005).

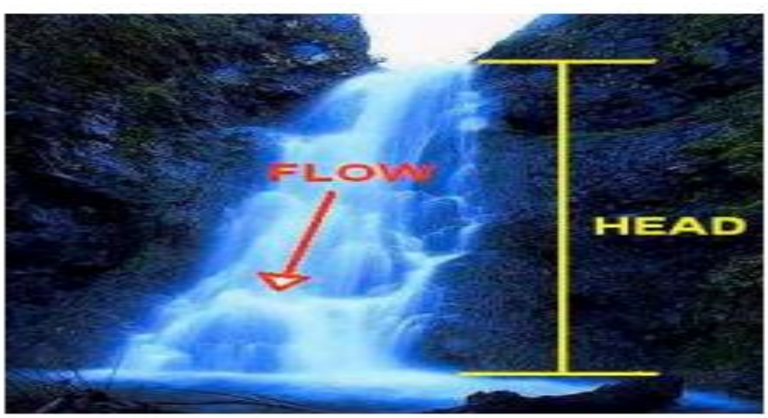

Figure 2.5: Head and Flow of a river

Source: The British Hydropower Association, 2005

2.8 EXTERNAL PARAMETERS

The external parameters determine how much water is to be lifted and usually determined by the location of the screw blade. External parameters are the outer radius, length and slope. This parameters determined the performance of the screw.

2.8.1 Outer Radius

The outside diameter, D of the screw pump in combination with the diameter of the centre tube are essential factors for the capacity of the pump. For long screw pumps a larger centre tube will be required to control the deflection, but this will have an effect on the effective capacity (Gerald Muller, Simplified Theory, 2009).

Outer radius of the screw blade determines the size of the screw. The larger the screw, the larger the volume of water that it can pass and the greater the quantity of energy that it can generate. The diameter of the screw play an important role in determines the rotational speed of the screw runner. The smaller the screw blade, the higher the rotational speed rpm (Kibel et al., 2011).

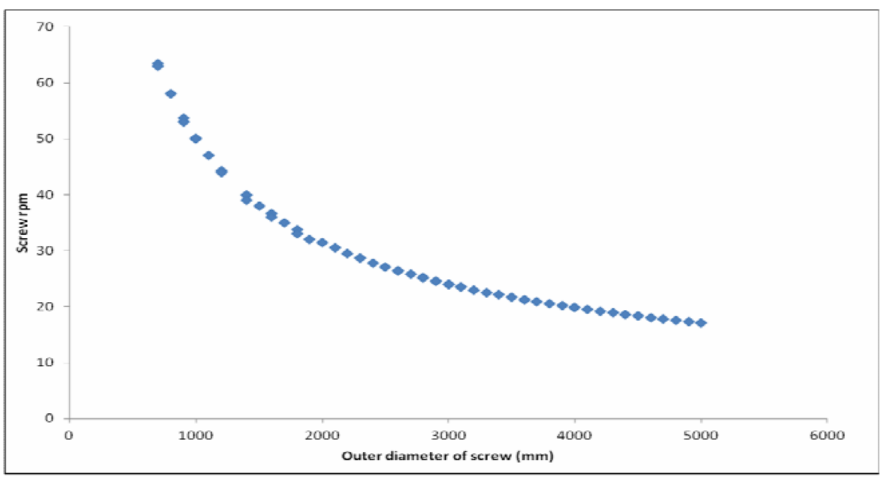

Figure 2.6 : Relationship between screw diameter and rotational speed rpm of a screw turbine

Source: Kibel et al., 2011